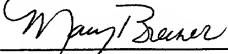


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|---|--|--|--|
| FORM PTO-1100<br>(2-97)   |  | U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE  |  |
| TRANSMITTAL LETTER TO THE UNITED STATES<br>DESIGNATED/ELECTED OFFICE (DO/EO/US)<br>CONCERNING A FILING UNDER 35 U.S.C. 371  |  | ATTORNEY'S DOCKET NUMBER<br>5373<br>U.S. APPLICATION NO. (If known, see 37 CFR 1.5)<br>097700033 |  |
| INTERNATIONAL APPLICATION NO.<br>PCT/DE99/01485   | INTERNATIONAL FILING DATE<br>12 May 1999 | PRIORITY DATE CLAIMED<br>12 May 1998   |  |
| TITLE OF INVENTION<br>METHOD OF AND APPARATUS FOR DRYING PHOTO RESIST LAYERS  |  |  |  |
| APPLICANT(S) FOR DO/EO/US Dr. Bernd LOCHEL, Andreas MACIOSSEK,<br>Gerhard BLEIDIESSEL, Wilhelmus WILBERS  |  |  |  |
| Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:   |  |  |  |
| 1. <input checked="" type="checkbox"/> This is a FIRST submission of items concerning a filing under 35 U.S.C. 371.<br><input type="checkbox"/> This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371.   |  |  |  |
| 2. <input checked="" type="checkbox"/> This express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).  |  |  |  |
| 4. <input checked="" type="checkbox"/> A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.  |  |  |  |
| 5. <input checked="" type="checkbox"/> A copy of the International Application as filed (35 U.S.C. 371(c)(2))   |  |  |  |
| a. <input type="checkbox"/> is transmitted herewith (required only if not transmitted by the International Bureau).<br>b. <input type="checkbox"/> has been transmitted by the International Bureau.<br>c. <input type="checkbox"/> is not required, as the application was filed in the United States Receiving Office (RO/US).  |  |  |  |
| 6. <input checked="" type="checkbox"/> A translation of the International Application into English (35 U.S.C. 371(c)(2)).   |  |  |  |
| 7. <input type="checkbox"/> Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))  |  |  |  |
| a. <input type="checkbox"/> are transmitted herewith (required only if not transmitted by the International Bureau).<br>b. <input type="checkbox"/> have been transmitted by the International Bureau.<br>c. <input type="checkbox"/> have not been made; however, the time limit for making such amendments has NOT expired.<br>d. <input type="checkbox"/> have not been made and will not be made. |  |  |  |
| 8. <input type="checkbox"/> A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).   |  |  |  |
| 9. <input checked="" type="checkbox"/> An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). (unexecuted)  |  |  |  |
| 10. <input checked="" type="checkbox"/> A translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).  |  |  |  |
| Items 11. to 16. below concern document(s) or information included:   |  |  |  |
| 11. <input checked="" type="checkbox"/> An Information Disclosure Statement under 37 CFR 1.97 and 1.98.   |  |  |  |
| 12. <input type="checkbox"/> An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.  |  |  |  |
| 13. <input type="checkbox"/> A FIRST preliminary amendment.<br><input type="checkbox"/> A SECOND or SUBSEQUENT preliminary amendment.   |  |  |  |
| 14. <input type="checkbox"/> A substitute specification.  |  |  |  |
| 15. <input type="checkbox"/> A change of power of attorney and/or address letter.   |  |  |  |
| 16. <input checked="" type="checkbox"/> Other items or information: Certified English Translation of the International Preliminary Examination Report including amended claims 1-15.  |  |  |  |

|  |              |  |            |  |    |
|--|--------------|--|------------|--|----|
| 097700033  |              | INTERNATIONAL APPLICATION NO<br>PCT/DE99/01485 |            | ATTORNEY'S DOCKET NUMBER<br>5373   |    |
| 17. <input checked="" type="checkbox"/> The following fees are submitted:<br><b>BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):</b><br>Search Report has been prepared by the EPO or JPO ..... \$ 860.00<br>International preliminary examination fee paid to USPTO (37 CFR 1.482) ..... \$ 690.00<br>No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) ..... \$ 710.00<br>Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO ..... \$1000.00<br>International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) ..... \$ 100.00<br><br><b>ENTER APPROPRIATE BASIC FEE AMOUNT =</b> |              |  |            | CALCULATIONS PTO USE ONLY  |    |
|  |              |  |            | \$ 860.00  |    |
| Surcharge of \$130.00 for furnishing the oath or declaration later than months from the earliest claimed priority date (37 CFR 1.492(e)). <input type="checkbox"/> 20 <input checked="" type="checkbox"/> 30   |              |  |            | \$ 130.00  |    |
| CLAIMS   | NUMBER FILED | NUMBER EXTRA                                   | RATE       | \$   |    |
| Total claims   | 17 - 20 =    | 0  | x \$ 18.00 | \$ 0.00  |    |
| Independent claims   | 2 - 3 =      | 0  | x \$ 80.00 | \$ 0.00  |    |
| MULTIPLE DEPENDENT CLAIM(S) (if applicable)  |              |  |            | \$ 270.00  |    |
| <b>TOTAL OF ABOVE CALCULATIONS =</b>   |              |  |            | \$ 1260.00   |    |
| Reduction of 1/2 for filing by small entity, if applicable. A Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28).   |              |  |            | \$ 0.00  |    |
| <b>SUBTOTAL =</b>  |              |  |            | \$ 1260.00   |    |
| Processing fee of \$130.00 for furnishing the English translation later than months from the earliest claimed priority date (37 CFR 1.492(f)). <input type="checkbox"/> 20 <input type="checkbox"/> 30   |              |  |            | \$ 0.00  |    |
| <b>TOTAL NATIONAL FEE =</b>  |              |  |            | \$ 1260.00   |    |
| Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property +   |              |  |            | \$   |    |
| <b>TOTAL FEES ENCLOSED =</b>   |              |  |            | \$ 1260.00   |    |
|  |              |  |            | Amount to be refunded:   | \$ |
|  |              |  |            | charged:   | \$ |
| 4. <input checked="" type="checkbox"/> A check in the amount of \$ <u>1260.00</u> to cover the above fees is enclosed.   |              |  |            |  |    |
| b. <input type="checkbox"/> Please charge my Deposit Account No. _____ in the amount of \$ _____ to cover the above fees. A duplicate copy of this sheet is enclosed.  |              |  |            |  |    |
| c. <input checked="" type="checkbox"/> The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. <u>02-3690</u> . A duplicate copy of this sheet is enclosed.  |              |  |            |  |    |
| <b>NOTE:</b> Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137 (a) or (b)) must be filed and granted to restore the application to pending status.  |              |  |            |  |    |
| SEND ALL CORRESPONDENCE TO:<br>Breiner & Breiner<br>115 North Henry Street<br>P.O. Box 19290<br>Alexandria, VA 22320-0290  |              |  |            |  |    |
|  |              |  |            | <br>SIGNATURE |    |
|  |              |  |            | Mary J. Breiner<br>NAME  |    |
|  |              |  |            | 33,161<br>REGISTRATION NUMBER  |    |
| Date: November 9, 2000   |              |  |            |  |    |

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### Method of and Apparatus for Drying Photo Resist Layers

The present invention relates to a method of and an apparatus for drying photo resist layers, particularly for micro system and precision mechanics technologies.

Within the general scope of manufacturing engineering in micro system and precision mechanics technologies the production of a mask by means of photo resist materials is a decisive step of process.

Photo resists are customized multi-material systems used for the production of micro electronic components, multi-layer systems and micro mechanical parts. The great variety of photographic, chemical and mechanical demands in the production process can be satisfied only by means of appropriately matched photo resists. The photo resists are multi-component systems consisting of a polymer binding agent, a photoactive component and a mixture of solvents. The polymer binding agent determines the physical properties, the photoactive component produces its effects on the photochemical process, and the mixture of solvents takes an influence on the characteristics of the resist system in the drying process. The mixture of solvents is composed in a manner that a solvent is contained which has a high steam pressure for accelerating or enhancing the stripping of the solvent mixture from the photoresist during the drying process.

The drying of the photo resists as immediate pre-stage preceding the photolithographic operation in the manufacturing process is considered a very sensitive step in the process. The physical drying of the photo resists must be so performed that a complete removal of the solvent mixture will be achieved.

In advanced manufacturing lines in the field of microelectronics the wafers are coated, as a rule, with the resist on a centred centrifuge rotating with a speed of roughly 5000 rpm. The thickness of the resist varies normally between 0.5  $\mu\text{m}$  in the case of plane or planed surfaces and 2  $\mu\text{m}$  with surfaces presenting distinct steps. The drying is finally performed on a hot plate at 100 °C approximately for complete stripping of the solvent. Then the photo resist is adjusted and exposed in a specific wafer exposure unit.

The period required for drying thicker wafers ( $\geq 40 \mu\text{m}$ ), which are required in micro mechanics in particular, lasts, as a rule, for 16 to 20 hours per lot, however, when this conventional technique is applied so that this step is a bottleneck in the production line.

Moreover, resist blisters may form during the drying process for thicker layers because for these applications the photo resist contains a high fraction of binding agent and a low viscosity. The blisters occur to an even higher extent during the drying operation in the furnace and on a hot plate. These blisters are solvent gas bubbles which remain adhered in the dried photo resist. These blisters may reach a height of several hundreds of  $\mu\text{m}$  and, during the subsequent exposure in the production line, extremely impair the structure resolution (proximity effect).

The European Patent EP 0 509 962 A1 discloses a method of drying photo polymers on metallised substrates, wherein the layers are dried by means of infrared radiation (IR radiation). That publication deals specifically with the so-called crawling or curtain coating in PC board technology, which permits the rapid and efficient drying of thin layers in the range of  $15 \mu\text{m}$ . This method is not suitable, however, for integration into a production line for the manufacture in micro system technology. Moreover, the mere exposure of thick layers ( $\geq 20 \mu\text{m}$ ) to IR radiation, which is required in micro system technology, does not lead to satisfactory results with respect to the surface quality of the dried layers. Compared against PC board technology, the surface quality of the photo resists is very important, however, in micro system technology for the creation of high-resolution structures.

The present invention is now based on the problem of providing a method and an apparatus which permit an operation of drying photo resist layers having a thickness of more than  $20 \mu\text{m}$  within a reasonable time, which operation is integrated into the process. Furthermore, the drying process should be suitable for various resists of different thicknesses and of different resist/substrate combinations as well as allow for the production of masks presenting a high imaging precision.

This problem is solved with the method and the apparatus according to the valid Patent Claims 1 and 8. Expedient embodiments are the subject matters of the dependent claims.

This method and the appertaining apparatus make it possible to achieve a dramatic reduction of the drying periods by roughly 80 % of the known drying methods, as well as distinct energy savings. The drying method results in homogeneous photo resists thoroughly dried

in a uniform manner, thus permitting a reduction of the exposure times for strata having rising structures.

So far, a drying technique has not become known for the micro system technology, which dries liquid photo resists having a stratum thickness of more than 20 nm and including rising structures in such a short time and with an adequate quality. The drying operation does not result in a chemical change in the resist material.

The inventive method and the inventive apparatus entail a substantial technological prerequisite for the application in micro system technology, which satisfies the demand for ever shorter periods of technological treatment of components. At the same time, the inventive method opens up the possibility of dimensionally true galvanic duplication moulding of micro-mechanical components and of building up multi-layer systems in superimposed relationship.

The inventive method and the apparatus were suitable for the manufacture of products which could so far not be produced with the achieved precision by means of any other drying method.

In the inventive method a substrate with the photo resist layer applied thereon is exposed to IR radiation in a deaerated process chamber whilst, at the same time, the temperature or a parameter dependent on temperature is measured in the vicinity of the photo resist layer. The power of the source of IR radiation is controlled and adjusted in real time as a function of the measured temperature or the parameter dependent on the temperature, respectively (e.g. electrical resistance) for the achievement of a predetermined development of temperature versus time in the vicinity of the photo resist layer. This closed-loop control permits an optimum selection of the development of the drying condition of the layer for the respective combination of the resist material and the substrate.

The space enclosed by the process chamber may be considered the vicinity of the photo resist layer. The measurement of the temperature at a location as close as possible to the photo resist layer is preferable, however.

The development of temperature  $T(t)$  ( $T$ : temperature;  $t$ : time) may be selected to be constant ( $T(t) = T_0 = \text{const}$ ) so that the temperature does not vary during the drying operation. The temperature level is set in correspondence with the selected resist and substrate materials. The optimum parameters, i.e. the temperature level and the period of radiation, as

well as a possible variation of the temperature throughout the drying period can be determined in an optimum manner by experimental approaches. For the temperature level an upper limit must, of course, be respected above which the respective photo resist will be destroyed.

The inventive apparatus consists preferably of a chamber adapted to be deaerated and comprising an air inlet and an air outlet for removal of the solvents discharged from the photo resist. Inside the chamber, an IR emitter is disposed above a substrate mount, which is preferably adapted for being vertically adjusted. The substrate mount is preferably rotatable and adapted to receive several substrates at the same time. A thermometric sensor detects the temperature during the drying operation. Moreover, a controller is provided which controls the power of the IR emitter as a function of the measured temperature in such a way that a development of the temperature versus time, which can be predetermined, may be realised on the measuring site of the thermometric sensor.

The present invention will now be described in the following in more details by embodiments with reference to the drawing wherein

Fig. 1 shows an embodiment of the inventive apparatus for drying photo resist layers;

Fig. 2 represents an example of a predeterminable development of the temperature versus time, which includes a ramp;

Fig. 3 shows an example of an application of the inventive drying method in the production of pressing springs for read/write heads for hard disks;

Fig. 4 is a microscopic picture of a structure, which can be realised when the inventive drying method is applied;

Fig. 5a is a plan view of an example of a particularly expedient receiving device for accommodating substrates or wafers in the inventive apparatus; and

Fig. 5b shows a cross-sectional view of a circular single mount of the receiving device shown in Fig. 5a.

Fig. 1 is a skeleton diagram of one embodiment of an inventive IR drying system. It consists substantially of three functional elements, the furnace proper (deaeratable chamber) 1 with a receiving means 5 for accommodation of a defined number of wafers 12 having the dimensions 4" and 6", an IR radiation source 4 with the appertaining mains supply unit 9 and

the controller module 8. The controller module combines the controlling hardware and software as well as the necessary computing means, which are provided to control the power of the IR radiation source.

The required floor space of the total system amounts to 0.9 m<sup>2</sup> approximately for this example. The power consumption of the IR radiation source corresponds to 4 kW. The power to be drained can be controlled from 9 to 100 %.

The detection of the temperature is fundamentally important for a controlled process management. To this end two different thermometric sensors 6, 7 are provided in the present case. The two thermometric sensors, a pyrometer 7 and a temperature-dependent resistor 6 (PT100), may be employed as complementary elements for process management. It is understood, of course, that other thermometric sensors such as thermo elements may be used as well. It is likewise not necessary to provide two separate thermometric sensors, as in the present case. Rather one thermometric sensor is sufficient, preferably a PT100 element, which furnishes the temperature data or a measurand, respectively, to the controller module 8, which measurand presents an invariable relationship with the temperature.

Based on the drying operations so far performed by means of the illustrated system with different photo resist/substrate combinations and with different thicknesses of the photo resist layer, it has been possible to find that an IR radiation source rated for a power of 2.5 kW is sufficient for the majority of applications.

With a precise temperature measurement along the path of the IR rays being very expensive, the thermometric sensors are disposed in the present apparatus underneath the wafer mount 5 for measuring the relative temperature of the surrounding air or the surrounding gas, respectively. On the whole, temperature measurement outside the radiation, i.e. outside the region between the IR emitter and the wafer mount, is to be preferred.

In the apparatus illustrated in Fig. 1, an air inlet 2 and an air outlet or exhaust-air outlet 3 are provided in the chamber 1. An additional controllable fan 13 is arranged on the air inlet 2. The infrared radiation source 4 is adapted to be vertically adjusted by means of an adjusting means 10 via the rotatable mount 5 for the wafers 12 onto which the photo resist layer is applied. The IR radiation source 4 may be formed, for instance, of a mount for four IR tubes disposed in parallel with each other at a spacing of roughly 10 cm. The radiation source is supplied via a controllable mains supply unit 9. The power of the mains supply unit 9 is controlled by the controller unit 8.

The receiving means 12 for accommodating wafers is formed by a rotary sample plate which receives several wafers in a star-shaped arrangement. In the present case, this rotary plate has a diameter of roughly 40 cm and can be rotated at a speed of 1 to 5 min<sup>-1</sup> approximately. The rotating speed is equally predetermined by the controller unit 8. A speed of less than 5 min<sup>-1</sup> is preferably selected in order to prevent the photo resist from spreading due to centrifugal forces. The rotary movement is created by the motor 11. The spacing of the IR radiation source from the rotary plate corresponds to 20 cm approximately in the present case. The rotation of the wafers under the radiation source expediently induces a homogeneous drying of the layers provided on the wafers, with the possibility to dry several wafers at the same time.

The air supply (cold air) and exhaust (warm air) implemented in the process leads to the establishment of a dynamic temperature equilibrium.

The plan view of Fig. 5a shows one example of a particularly expedient receiving means for accommodating substrates or wafers, respectively, in the inventive apparatus. The substrate mount (5) is made of stainless steel and, according to the present example, comprises six single mounts (14) in a star-shaped arrangement for receiving six wafers (12). It is, of course, also possible to select an arrangement including a higher or smaller number of individual mounts. For round wafers, circular rings with a recess (15) are used as single mounts so that the transfer of the wafers from a pair of tweezers into the rings will be possible. The wafers (12) are expediently supported only along the edge over a width of some 0.5 mm so that a noticeable transfer of heat to the wafer mount cannot occur.

This design of the receiving device presents, on the one hand, the advantage that the wafers (with the photo resist) can be heated in the IR ray more rapidly because of the lack of heat transfer to the mount. On the other hand, the expedient advantage is achieved that the same conditions prevail with respect to the heat transfer during each drying operation because there is no thermal coupling to the substructure. By contrast, a support over the total area on a base plate would not give rise to constant heat transmission conditions due to a possibly non-uniform support.

The sectional view in Fig. 5b shows a circular individual mount (14) of the receiving means according to Fig. 5a. The individual mount has a height of roughly 10 mm along the outer periphery. The supporting area (16) with a wafer (12) supporting width of roughly 0.5 mm can be clearly seen in the sectional view.



The implementation of the control function with respect to the temperature in the vicinity of the layers is necessary in order to achieve proper drying results. Tests have gone to show that from the viewpoint of a sound process management a temperature variation from the predetermined temperature development by less than 0.5 °C should be observed. The precise definition and measurement of the temperature behaviour of the system as a function of the IR emitter power is the prerequisite for a precise control. These values must be integrated into the control algorithm of the controller unit. To this end, a specific software is expediently applied. Hence, the advantage of flexible software control is benefited from. It is possible to predetermine or to develop and use specific control algorithms for the respective different photo resist and substrate combinations.

The controller unit makes it possible to control the IR radiation source over a power range from 0 to 100 %. Via the input of supporting locations, it is possible to implement step- or ramp-shaped temperature graphs.

Table 1 is a survey of different carrier substrates onto which a photo resist layer, 50 µm thick, could be subjected to an inventive drying operation.

In the operation of drying photo resists based on novolak, attention must be paid to the aspect, on principle, that the resist will not be modified or decomposed. The thermal stability of the photosensitive component restricts the maximum temperature which may occur during the drying operation. Photo resists on novolak basis are stable up to a temperature level of roughly 100 to 110 °C. The precise decomposing temperature of some photo resists can be determined by means of UV-VIS spectroscopy. In such an investigation the absorption spectrum of the photo resists (photosensitive component) at different drying temperatures is compared and then the decomposition is concluded via the modification. The photo resists for microelectronics and micro system technology are mostly sensitive to ultraviolet light and absorb wavelengths between 340 nm and 405 nm.

The precise determination of the reaction rate of the decomposition and evaporation reaction should be initially performed for each resist. It is very important to establish these reaction parameters for the development of drying parameters optimised in terms of time, because with such an approach the upper limits of the drying temperature and the drying time can be determined in an optimum manner.

Table 2 shows various substrate/resist combinations (commercially available by the designation AZ® 4562 of the Hoechst company or ma-P100 of the company of micro resist tech-

nology GmbH) as well as combinations of different resist layer thicknesses which could be dried in an optimum manner with the drying parameters given there, i.e. emitter power and drying period (time).

| Substrate                               | thickness in $\mu\text{m}$ | IR suitability |
|---|----------------------------|----------------|
| polished silicon wafer                  | 525                        | positive       |
| polished Si wafer with 100 nm Au        | 525                        | positive       |
| Si wafer with 1 $\mu\text{m}$ aluminium | 500                        | positive       |
| Si wafer with 100 nm oxide              | 525                        | positive       |
| Pyrex with 100 nm Au                    | 525                        | positive       |

**Table 1**

| Substrate/4" silicon wafer<br>525 $\mu\text{m}$ thick | resist type | resist thickness ( $\mu\text{m}$ ) | drying parameters |                   | resolution ( $\mu\text{m}$ ) |
|---|-------------|------------------------------------|-------------------|-------------------|------------------------------|
|   |             |                                    | time(s)           | emitter power (%) |                              |
| Si + Si/Au 100 nm                                     | ma -P100    | 55 - 60                            | 3600              | 62                | 10                           |
| Si + Si/Au 100 nm                                     | ma -P100    | 40                                 | 3600              | 59                | 10                           |
| Si + Si/Au 100 nm                                     | ma -P100    | 55                                 | 900               | 67                | 10                           |
| Si + Si/Au 100 nm                                     | ma -P100    | 57                                 | 1200              | 67                | 10                           |
| Si monitor  | AZ4562      | 32                                 | 3600              | 58                | 7                            |
| Si + Si/Au 100 nm                                     | AZ4562      | 55                                 | 3600              | 62                | 20                           |
| Si + Si/Au 100 nm                                     | AZ4562      | 100                                | 3600              | 67                | 30                           |

**Table 2**

The emitter power is related to the maximum power of 4 kW of the radiation source which is employed here. The structural resolution of the masks that can be produced from the photo resist layers subsequently is equally indicated.

Silicon wafers with nickel surfaces can be dried with the same parameters. The resist thickness in the table must be considered to correspond to the upper limit. Thinner layers can be dried within a correspondingly shorter period.

Fig. 4 illustrates one example of a created structure that could be produced by means of the mask produced from a photo resist layer dried in accordance with the present invention. For mask production a photo resist layer, 60  $\mu\text{m}$  thick, was dried by the inventive IR drying method whereupon a mask was produced by means of photolithography and then galvani-

cally duplicated with nickel. The thickness of the webs shown in the microscopic picture amounts to 20  $\mu\text{m}$  approximately.

The principal field of application of the IR drying operation are highly viscous and high-resolution photo resists. These resists are predominantly exposed by means of contact exposing devices. Contact exposing devices operate on the shadow-casting principle. The mask structure is transferred into the resist at a ratio of 1 : 1. This means that the resolution capacity of the lithography is correlated to the distance by which the mask is spaced from the photo resist.

After IR drying the resist surface must therefore be as plane as possible so that a small spacing from the lithographic mask will be achieved. This intention, however, is confronted with the problems of marginal bead formation when the resist is centrifuged and of blister formation during the drying operation.

The cause of such a marginal bead resides in the surface tension from the resist to the substrate and in the high viscosity.

In the "spin-on" method (resist application process), the resist is applied on the centre of the wafer and the wafer is then caused to rotate. A resist layer of varying thickness is then formed as a function of time and speed of rotation. Excessive resist material remains on the wafer edge, which contracts to form a bead. This bead can be removed prior to exposure by a centrifuging process with a solvent.

The situation is different with resist blisters, which may form during the drying process. These blisters may reach a height of several hundreds of  $\mu\text{m}$  and therefore be extremely detrimental to the structural resolution during the exposure. Even though the blistering effect is distinctly reduced already by the IR drying operation, it can be additionally suppressed almost completely by the appropriate selection of a suitable development of temperature versus time.

To this end the photo resist is maintained in a sufficiently liquid state during the drying operation, e.g. by a continuous increase in temperature, so that any gas produced can still leave the surface of the resist. What is important is the fact that the temperature rises towards the end of the drying operation. The resist retains a sufficient viscosity even though some solvent is permanently evaporated.

Fig. 3 illustrates a development of the temperature versus time for the suppression of a blistering effect. The temperature levels for the constant temperature range and the maximum temperature b the end of the temperature development correspond to 90 and 105 °C, for example. These values are, however, dependent on the resist materials to be dried. With application of the inventive apparatus comprising the controller unit 8 in combination with the thermometric sensors and the control of the IR radiation source it is possible, without any problems, to implement such a development through a temperature ramp. This is particularly expedient as the blistering tendency increases particularly as the thickness of the photo resist layer to be dried increases.

With the inventive method or the inventive apparatus, respectively, it is possible, for example, to manufacture pressing springs for read/write heads for hard disks with a high precision. Such a manufacturing process, which includes an inventive IR drying operation, is illustrated in Figures 3A and 3B. There a silicon wafer (diameter: 4" or 10 cm) is used as carrier substrate. A metal layer is applied onto this substrate, which acts as galvanic starter layer. Then some photo resist material is applied by centrifuging (Step No. 3), subjected to the inventive drying operation (Step No. 4), exposure and development. The micro spring is now created by a galvanic filling of the photo resist structure. In the last step, the micro spring is detached from the silicon substrate by two etching processes.

In this exemplary case, a maximum radiation power of 4 kW was equally applied. So far, it has not been possible to manufacture such pressing springs for read/write heads with the required precision.

In each of the aforescribed embodiments, a respective IR radiation source with a power of 4 kW was employed. With appropriate drying conditions, the maximum of the IR radiation corresponds to roughly 2.6  $\mu\text{m}$ . This must be understood, however, as an example only. As a matter of fact, radiation sources of different power levels and emitting at different maximum wavelengths may be employed, of course, in due consideration of each application.

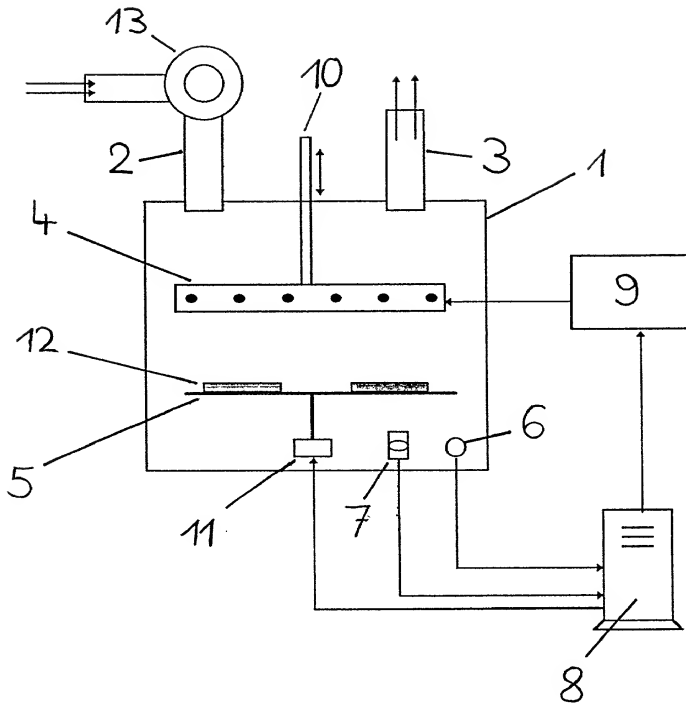
**Patent Claims**

1. Method of drying photo resist layers, wherein a substrate (12) with a photo resist layer applied thereon is exposed to IR radiation from an IR radiation source (4) whose power is controllable, in a deaerated chamber, wherein the temperature or a temperature-dependent parameter is measured in the vicinity of said photo resist layer, and the power of said IR radiation source is controlled on the basis of the measured temperature or said temperature-dependent parameter, respectively, in such a way that a predetermined development of the temperature versus time will be observed during the drying operation, characterised in that said predetermined development of the temperature versus time is so selected that the temperature is initially constant and then undergoes a linear, step-shaped or any other increase throughout the drying operation.
2. Method according to Claim 1, characterised in that the temperature is measured underneath said substrate.
3. Method according to any of the Claims 1 to 2, characterised in that the temperature of the area covered by said photo resist is measured from the upper side by means of a pyrometer, with the different emissivity of said substrate, on which the photo resist layer to be dried is applied, being taken into consideration.
4. Method according to any of the Claims 1 to 3, characterised in that the predetermined development of temperature versus time is initially experimentally established for each new combination of materials for said photo resist layer and said substrate.

5. Method according to any of the Claims 1 to 4,  
characterised in that the quantity or the concentration of solvents is detected in circulated air, preferably in an air circulation line issuing from said chamber, and that when the measured value drops below a predeterminable limit the completion of the drying process is initiated by down-control of the power of said IR radiation source.
6. Method according to any of the Claims 1 to 5,  
characterised in that an IR radiation source is employed which has its maximum in IR radiation within the range from 1 to 3  $\mu\text{m}$ .
7. Method according to the Claims 1 to 6,  
characterised in that when the photo resist layers of several substrates, which perform a rotary movement about an axis in the chamber, are dried simultaneously the temperature measurement is controlled in such a timed manner that for each passage of one of the substrates through a measuring field where the temperature is measured a measurement is performed.
8. Apparatus for drying photo resist layers, consisting of a deaeratable chamber (1) comprising an air inlet (2) as well as an air outlet (3), an IR radiation source (4) disposed in said chamber above a substrate mount (5) and controllable in terms of its power, a thermometric sensor (6, 7) provided in said chamber, as well as a controller unit (8) which controls the power of said IR radiation source as a function of the measured temperature in such a way that during the drying operation a predeterminable development of the temperature versus time will be observed in said chamber,  
characterised in that said substrate mount (5) comprises several individual substrate mounts (14) which are so configured that the substrate is supported only on a narrow edge.

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9. Apparatus according to Claim 8,  
characterised in that said IR radiation source (4) is disposed for vertical adjustment above said substrate mount (5).
10. Apparatus according to any of the Claims 8 or 9,  
characterised in that said substrate mount (5) is so designed that it is adapted to receive several substrates (12) in a star-shaped juxtaposed arrangement.
11. Apparatus according to any of the Claims 8 to 10,  
characterised in that said substrate mount (5) is rotatably supported and adapted to be rotated at a predeterminable rotary speed by means of a motor (11) whose speed of rotation is controllable.
12. Apparatus according to any of the Claims 8 to 12,  
characterised in that a controllable fan (13) is provided on said air inlet (2).
13. Apparatus according to any of the Claims 8 to 12,  
characterised in that said thermometric sensor (6) is constituted by a temperature-dependent resistor, a pyrometer or a thermo element.
14. Apparatus according to any of the Claims 8 to 13,  
characterised in that the maximum power consumption of said IR radiation source (4) ranges between 2.5 and 4 kW.
15. Apparatus according to any of the Claims 8 to 14,  
characterised in that a sensor is provided for measuring the quantity or the concentration of solvents, respectively, in circulated air, preferably in the air outlet or in an air circulation line issuing from said air outlet, which sensor produces an output signal adapted for use in the determination of the completion of the drying operation and in the down-control of the power of said IR radiation source.

Fig. 1



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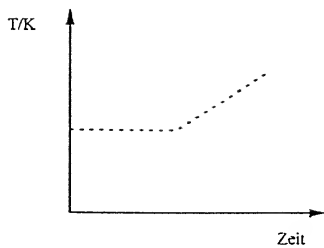
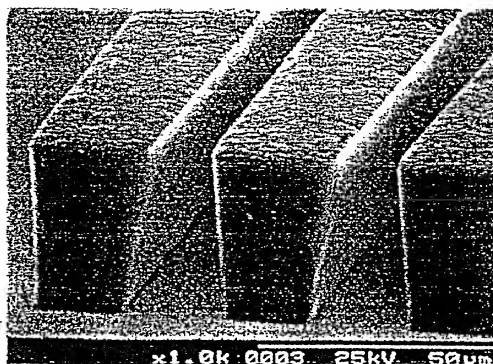




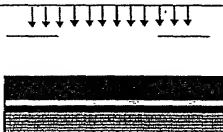





Fig. 2Fig. 4

Fig. 3a

| No. | Description of Process  | Process Layer                                 | Description   |
|-----|---|---|---|
| 1   | Application (sputtering) of an adhesive layer for the galvanic starter layer  | Silicon nitride (SiN)<br>80nm<br><br>Si wafer |    |
| 2   | Application (sputtering) of a galvanic starter layer  | Gold<br>100 nm                                |    |
| 3   | Centrifuged application of photo resist material<br>Apparatus: Suess company, model RC-8<br>15s 300 rpm '5 s 400 rpm<br>photo resist: company of mrt, type V100 | Photo resist<br>55 µm                         |    |
| 4   | IR drying:<br>900 s at 67 % of the maximum power  |   |    |
| 5   | Exposure to IR radiation:<br>Apparatus: Suess company, model Ma 56<br>Contact exposure unit<br>2210s at 18 mJ/cm²   |   |    |
| 6   | Development:<br>Developer: mrt company, type ma D 330<br>Exposure period: 10 min  |   |  |

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|    |  |                            |   |
|----|--|----------------------------|---|
| 7  | Galvanic deposition of nickel<br>Bath type: nickel sulfamate of the Blasberg company<br>Duration: 2.5 hours<br>Current: 10mA/cm <sup>2</sup> | Nickel<br>50 $\mu$ m       |  |
| 8  | Photo resist removal with acetone  |                            |  |
| 9  | Removal of the galvanic starter layer (gold) in a sputter etching process (ion milling)<br>duration: 180 s                                   | Photo resist<br>55 $\mu$ m |  |
| 10 | Detachment of the micro springs by selective removal of the adhesive layer (SiN), using 5 % hydrofluoric acid (HF)                           |                            |  |

**Fig. 3b**

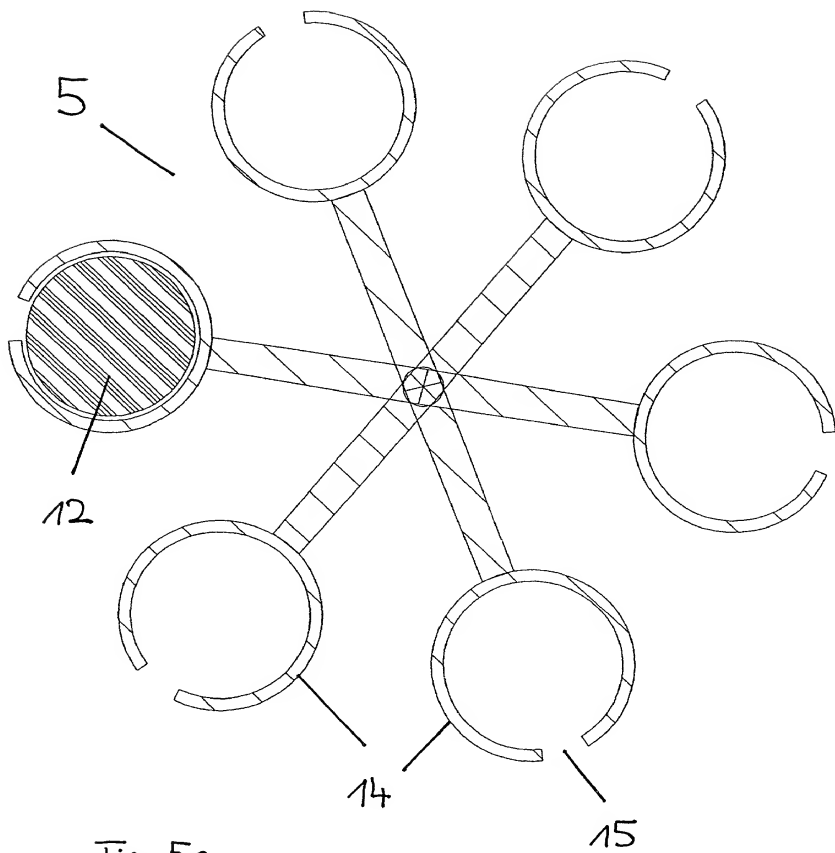
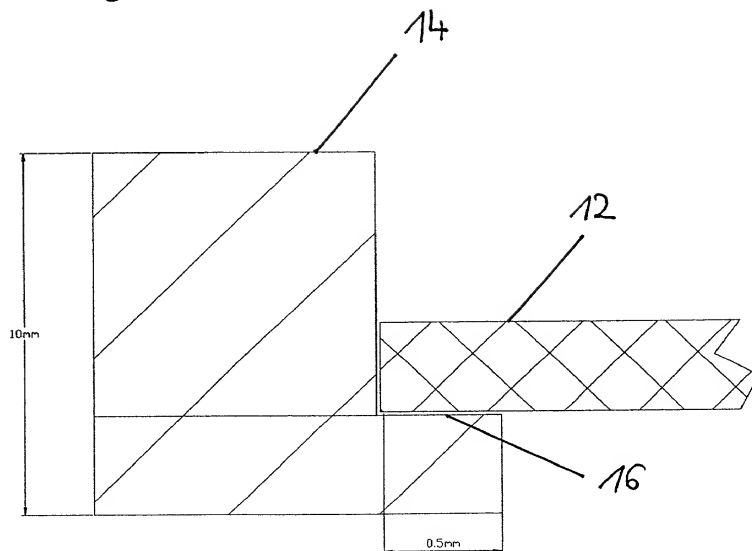


Fig. 5b

COMBINED DECLARATION AND POWER OF ATTORNEY  
FOR PATENT APPLICATION

Docket No. 5373

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled METHOD OF AND APPARATUS FOR DRYING PHOTO RESIST LAYERS,

the specification of which is attached hereto unless the following box is checked:

[X] was filed on May 12, 1999 as United States Application Number or PCT International Application Number PCT/DE99/01485 and was amended on \_\_\_\_\_ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR §1.56.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or §365(b) of any foreign application(s) for patent or inventor's certificate, or §365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)

Priority Claimed

198 212 37.2      Germany      12 May 1998  
(Number)                      (Country)                      (Day/Month/Year Filed)

Yes [X] No [ ]

PCT/DE99/01485      PCT      12 May 1999  
(Number)                      (Country)                      (Day/Month/Year Filed)

Yes [X] No [ ]

I hereby claim the benefit under 35 U.S.C. §119(e) of any United States provisional application(s) listed below.

\_\_\_\_\_  
(Application Number)

\_\_\_\_\_  
(Filing Date)

\_\_\_\_\_  
(Application Number)

\_\_\_\_\_  
(Filing Date)

I hereby claim the benefit under 35 U.S.C. §120 of any United States application(s), or §365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. §112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR §1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

\_\_\_\_\_  
(Application No.)

\_\_\_\_\_  
(Filing Date)

\_\_\_\_\_  
(Status-patented, pending, abandoned)

\_\_\_\_\_  
(Application No.)

\_\_\_\_\_  
(Filing Date)

\_\_\_\_\_  
(Status-patented, pending, abandoned)

I (we) hereby appoint the following attorney with full power of substitution to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

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COMBINED DECLARATION & POWER OF ATTORNEY

Docket No. 5373

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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COMBINED DECLARATION & POWER OF ATTORNEY

Docket No. 5373

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Inventor's Signature \_\_\_\_\_

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Citizenship: \_\_\_\_\_

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